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Expanding logistics support to science programmes in Antarctica: Long distance traverse capability development options for Antarctica New Zealand

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Abstract

New Zealand Antarctic Research Institute (NZARI) have recently launched a new multidisciplinary research programme; the Vulnerability of the Ross Ice Shelf in a Warming World (NZARI, 2014). A critical component of this project will be a programme of drilling undertaken at two sites, located 350km and 1000km respectively from Scott Base. One method of delivering the necessary logistical support required for this programme is conducting a long distance land traverse. By analysing data from recent traverse literature and commercial publications, and by consulting with staff from National Antarctic Programmes, equipment suppliers and manufacturers this study examines the capabilities required to conduct long distance traverses. It provides an overview of how those required capabilities may be met, and a high level analysis of the benefits of different systems. The study concludes that the addition of a medium weight tracked vehicle to the existing vehicle fleet, combined with the purchase of Ground Penetrating Radar equipment, flexible sleds, fuel bladders and a fully fitted mobile accommodation module would enable Antarctica New Zealand to develop a long distance traverse capability. Initial cost estimates indicate this could be achieved for under NZ$1million capital cost. Further detailed work is required to test this hypothesis and develop a detailed capability development plan.

Table of Contents

Annexes

Introduction - Strategic Context

Conducting the scientific research required to address the 80 scientific questions identified during the recent Antarctic and Southern Ocean science horizon scan will require expanded year round access to the Antarctic continent (Kennicutt II et al., 2014). Supporting inland bases and field parties in Antarctica is a significant logistical challenge, one that consumes a significant part of the budgets of National Antarctic Programmes. For example, logistics consumes approximately 90% of the budget of the US Antarctic Programme (U.S. Antarctic Program Blue Ribbon Panel, 2012). Reducing support costs is a significant challenge that all Antarctic programmes will continue to face as they seek to address the 80 questions (Sanchez & Njaastad, 2013).

In recent years significant cost savings have been made by replacing parts of some previously entirely air resupply operations with overland traverses (U.S. Antarctic Program Blue Ribbon Panel, 2012). These include a large proportion of the resupply of South Pole station. This was first conducted by land traverse in 2005 (Weale & Lever, 2008). Compared to air resupply, land traverse operations “emit less 1% the pollutants, consume half the fuel and save $1.6million for each delivery of 320,000kg of fuel” (Lever & Weale, 2012).

Current land traverse operations generally comprise a lead route finding and proving vehicle equipped with Ground Penetrating Radar followed by a number of vehicles towing loads. These include loads of cargo and fuel for the destination, fuel for the vehicles on the operation and modules that support the crew, including living quarters and stores of maintenance equipment and spares (Hoffman & Voels, 2012). The crews generally comprise drivers for each vehicle, a radar operator, a small maintenance crew and field support staff member. The South Pole Traverse in 2009/10 consisted of 9 vehicles crewed by 10 people (Thur, 2012). Travel is at speeds of between 8 and 11 kilometres per hour (Lever & Weale, 2012) and operations can be up to 45 days in duration (Weale & Lever, 2008).

In recent years a number of National Antarctic Programmes (NAP) have developed traverse capability to support science programmes conducted at large distances from research bases. This has enabled science programmes to be conducted in areas which were previously beyond the reach of NAP logistics systems (T Thomas, personal communication, February 11, 2015). The limitations of air and aviation support associated with restrictions on the weight and size of loads, availability of platforms, and personnel and high operating costs have been overcome. New traverse capabilities include those developed by the British Antarctic Survey (BAS) and US Antarctic Programme (USAP) to support the iSTAR project (M Dinn, personal communication, February 02, 2015) and the Whillans Ice Stream Subglacial Access Research Drilling (WISSARD) project respectively (T Thomas, personal communication, February 11, 2015).

New Zealand Antarctic Research Institute (NZARI) have recently launched a new multidisciplinary research programme; the Vulnerability of the Ross Ice Shelf in a Warming World (NZARI, 2014). A critical component of this project will be a drilling programme. The programmes intent is to use a hot water drill at 2 sites on the Ross Ice Shelf, located approximately 350km and 1000km from Scott Base (Figure 1). At each site 3 separate holes will be drilled (T Bean, personal communication, February 13, 2015). Drilling is planned to take place at site 2 in summer season 2016/17 and at site 1 in 2017/18 (E Butler, personal communication, November 26, 2014). This programme will require a significant logistics effort. The component parts of the drill system weigh 6000kg in total. To drill and keep open for 10 days an 800m hole similar to that planned at site requires 8000L of fuel (T Bean, personal communication, 17 February 2015).

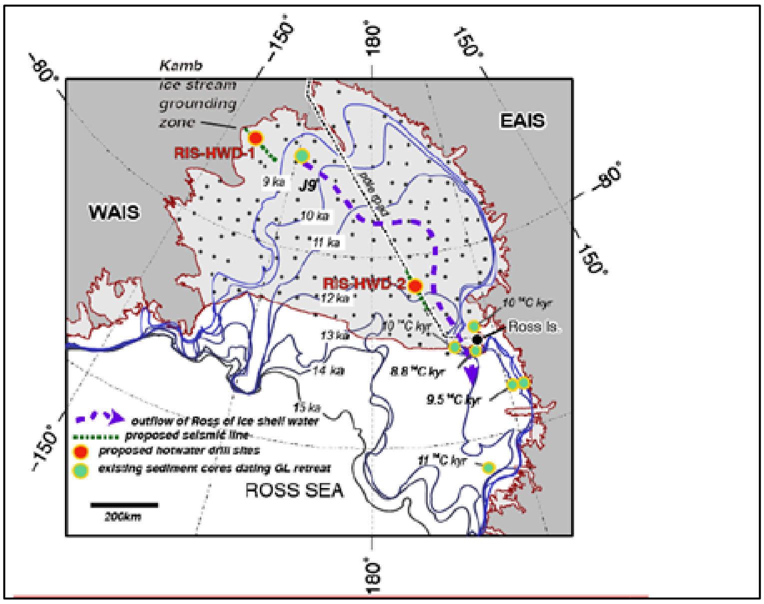

Figure 1. Ross Ice Shelf region showing location of planned drilling sites associated with the Vulnerability of the Ross Ice Shelf in a Warming World Programme. Figure from Antarctica New Zealand, 2014b.

Antarctica New Zealand have committed to “build logistics capability and improve Scott Base facilities to better support scientific research“ (Antarctica New Zealand, 2014). This includes seeking to extend the range of their logistics support that can be provided to “science programmes needing access to a wider coverage of the Ross Dependency” (Antarctica New Zealand, 2014). This will be essential if the planned drilling of the Ross Ice shelf is to take place. One method of achieving this is developing the ability to conduct long distance land traverse resupply operations.

Current Antarctic New Zealand Traverse Capability

Antarctica New Zealand operate a fleet of 35 vehicles from Scott Base (see Annex A). These include 2 x bulldozers, 1 x medium weight tracked vehicle (Pisten Bully 300), 6 x lightweight tracked vehicles (2 x Pisten Bully 100 and 4 x Haagland BV206) and 16 x skidoo. The remaining vehicles are either materiel handling equipment or wheeled vehicles with limited utility on snow and ice. Antarctica New Zealand own or have access to a number of different sleds and sled mounted huts or cargo containers. The sleds comprise a variety of different sizes. They include 8 x Haagland Sledges able to carry 2000kg, 4 x Cantago Sledges able to carry 4500kg, and 2 x Lehman Sleds which remain at Scott Base following the completion of the Andrill project (Watson, 2015). Lehman sleds are able to carry maximum loads of 10000kg to 25000kg depending on the variant (Garrod, 2012). The sledges are in varying states of repair. The amount of work required to ensure they are fit for use has not been fully detailed, but it is likely the work to ensure they are serviceable is minimal (Watson, 2015).

The 24 x sled mounted huts or cargo containers include refrigerated containers converted to mess facilities and basic accommodation huts. The 4 accommodation huts sleep 4 people, have basic heating systems, and are fitted with electrical power sockets. One is fitted with basic cooking facilities.

Using this equipment, Antarctica NZ have undertaken short distance traverses in support of science programmes in the last 10 years. These include 100km traverses conducted as part of the Andrill project and more recently a traverse to Granite Harbour, located approximately 150km from Scott Base on the Victoria Land Coast (P. McCarthy, personal communication, December 28, 2014). In both these traverses the D4 and D6 bulldozers were used to move the largest loads (Watson, 2015). These traverses generally involved operating the vehicles with limited rest stops and using tented field camps for equipment operators and crew. Conducted on routes which have been checked and established using crevasse detection systems operated by the USAP, the operations have achieved their objectives but have been inefficient. This is due to a number of factors including the slow speed of the bulldozers (approximately 5km/h) and fatigue on equipment operators. They have also had a significant short term impact on availability of equipment for other tasks.

Aim

This study examines the capabilities required to conduct long distance traverses, provides an overview of how those required capabilities may be met, and a high level analysis of the benefits of different systems. Its purpose is to provide Antarctica New Zealand with baseline information that will enable more detailed logistics support, long term asset management and capability development planning.

For planning purposes, the scope of the traverse capability has been based around the requirement to support the Vulnerability of the Ross Ice Shelf in a Warming World Programme. It considers the need to conduct an initial traverse of 350km and a subsequent traverse of 1000km which includes at least 50km off existing routes. Cargo volumes and weights are based on supporting the traverse and its crew plus an additional 10 person camp at its destination for 2 weeks. Fuel demand for drilling is based on drilling 3 holes at each site.

This study has been undertaken by analysing data from recent traverse literature and commercial publications and by consulting with staff from the US, New Zealand and British NAPs, and suppliers and manufacturers of relevant equipment. The tasks required to be undertaken as part of a traverse operation have been analysed and the factors that influence how those tasks are conducted have been examined. This has included an analysis of other constraints that affect the systems chosen for use in traverses such as maintenance space and facilities. These analyses have been used to enable the suitability of available systems to be evaluated. A high level examination of factors to be considered in implementation and recommendations for future work are included. Following consultation with Antarctica New Zealand the detailed examination of communications systems required are not included in the scope of the project.

Evaluation of Requirements

The requirements of a long distance traverse capability are determined by a number of factors; the tasks required to be undertaken before and after the traverse; to and from the destination; and at the destination. A breakdown of the main tasks undertaken during a traverse operation is at Annex B. Based on an analysis of these tasks required/requirements the following critical components of a traverse capability have been identified:

1. Cargo carrying and sled towing vehicles;
2. Cargo carrying system,;
3. Crevasse detection and avoidance system;
4. Route clearing and improvement system;
5. Crew and passenger transport system;
6. Crew and passenger accommodation and support system;
7. Cargo loading and unloading system;
8. Fuel supply and distribution system;
9. Communication system.

A number of options are possible to meet these capabilities. These will be examined, in order to provide an overview of available options. The options will then be evaluated to identify those deemed most appropriate for development of traverse capability by Antarctica New Zealand.

Efficiency of Traverse Operations

The efficiency of current traverse operations is limited by a number of factors (Weale & Lever, 2008). The pulling power of the vehicles and the ease with which load carrying sleds can move over snow, limit the weight of cargo that each vehicles can tow and the speed at which they can travel. The amount of fuel required to be carried for use by the vehicles and the need to carry loads to support the crew during the traverse, limits the carrying capacity of the vehicles. The high stress working conditions and resulting strain on personnel during these operations mean that sufficient rest must be included in the traverse schedule. This limits the travel time and therefore distance that can be travelled each day. The difficulties associated with finding a safe route, particularly identifying and avoiding crevasses means there is a high probability of delays due to vehicles becoming imobilised. Delays may also be caused by mechanical failures due to the very challenging operating conditions (for example extremely low temperature) and the difficulties of conducting repairs under those conditions.

Cargo Carrying and Sled Towing Vehicles

A range of different prime movers are used to tow loads and transport personnel in traverses (see Annex C). The main factors to be considered when determining the most appropriate vehicle include:

1. Carrying capacity (personnel and cargo).
2. Towing capacity which is a function of drawbar pull and ground pressure.
3. Fuel efficiency.
4. Fuel capacity.
5. Speed.
6. Ease of maintenance in field and at base.
7. Number and type of different accessories available.
8. Capital cost,
9. Operating costs,
10. Disposal costs,
11. Size and weight of vehicle.
12. Size and weight of engines and main assemblies.
13. Likely life span of vehicle.

The vehicles fit into 4 main categories; bulldozers; heavy; medium; and lightweight tracked vehicles. The main characteristics of these vehicle categories are at Table 1.

Vehicle Category	Main Characteristics
Bulldozers (e.g. Caterpillar D6 LGP or Caterpillar D4 LGP)	• Approx. 5m long, 3m high and 2.5 - 3m wide. • Ground Pressure approx. 4 - 5psi. • High drawbar pull. • Able to tow 50000 – 60000kg loads. • Single person cab. • Speed when fully laden/towing loads approx. 5km/h. • Fuel consumption approx. 5L/km
Heavy Vehicles (e.g. Caterpillar Challenger 765 or 865, Case Quad Track)	• Approx. 6-7m long, 3-4 m high and 3.5 -4m wide. • Ground Pressure approx. 6psi. • High drawbar pull. • Able to tow 50000 – 60000kg loads. • Max 2 person cab. • Speed when fully laden/towing loads approx. 12km/h.

	• Cost approx. NZ$700000. • Fuel consumption approx. 8L/km
Medium vehicles (e.g. Pisten Bully 300, Prinoth Everest, Berco TL6)	• Approx. 7m long, 3m high and 4 – 4.5m wide. • Ground Pressure approx. 1 - 2 psi. • Able to tow loads of approximately 40T. • Have snow clearing and grooming attachments. • Up to 5 person cab depending on type. • Single or two part platform. 2 platform types • HIAB Crane attachments. • Carry up to T on platform depending on type • Speed when fully laden/towing loads approx. 10km/h. • Cost approx. NZ$500000. • Fuel consumption approx. 3L/km
Light Vehicles (BV206, Pisten Bully 100)	• Approx. 6m long, 2.5m high and 2-3m wide. • Ground pressure approx. 2psi. • Able to tow loads of approximately 2500kg. • Some have snow clearing and grooming attachments. • Up to 5 person cab depending on type. • Single or two part platform. 2 platform types. • Carry up to T on platform depending on type • Speed when fully laden/towing loads approx. 10 – 12km/h • Cost approx. NZ$300000. • Fuel consumption 1-2 L/km.

Table 1. Main features of principal cargo carrying or towing vehicle categories.

Further considerations when determining the appropriate vehicle to use for cargo carrying/towing in a traverse include; extent of compatibility with existing fleet; quality of after sales support and technical advice; availability and; quality of training and platform availability/ procurement lead in time. Ideally the number of different types of vehicles in the fleet should be kept to a minimum in order to reduce the number of different spares and sets of specialist tools and test equipment that need to be held; to reduce the training required for operators and maintainers; and potentially to enable better prices to be negotiated though having greater purchasing power. For similar reasons compatibility of platforms with partner NAPs should also be considered. In the case of Antarctica New Zealand current workshop space and facilities are an important constraint on the size of vehicles that can be easily maintained. The workshop is fitted with 2 gantry cranes with 1 Ton and 2 Ton safe working limits respectively. Access to the workshop is limited by the size of the doors which measure 4.9m wide by 3.7m high.

A comparison of the main advantages and disadvantages of the different types of vehicle is at Table 2.

Vehicle Category	Advantages	Disadvantages
Bulldozers (e.g. Catterpillar D6 LGP or Catterpillar D4 LGP)	• Able to tow large weights greater than 50000kg.	• Half the speed of all other vehicles. • Limited versatility. • No cargo carrying capacity.
Heavy Vehicles (Caterpillar Challenger 765 or 865, Case Quadtrack)	• Able to tow weights greater than 50000kg.	• High Cost • High Ground Pressure • High fuel consumption. • Limited versatility. • Limited crew capacity. • High vehicle – unlikely to fit into Scott Base workshop.
Medium vehicles (Pisten Bully	• Low ground pressure but able	• Wide vehicle, blades need to be

300, Prinoth Everest, Berco TL6)	to tow 40000kg. • Versatile. Able to be configured for a variety of different tasks e.g personnel carrying, snow clearing. • Moderate Cost	removed to fit Scott Base workshop.
Light Vehicles (BV206, Pisten Bully 100)	• Versatile. Can be configured for a variety of tasks.	• Limited cargo carrying capacity. • Limited towing capacity (approx. 2500kg)

Table 2. Comparison of the advantages and disadvantages of different categories of cargo carrying and/or cargo towing vehicles.

Based on this evaluation of the different vehicle categories, it is apparent that medium weight vehicles like the Pisten Bully 300, Prinoth Everest or Berco TL6 provide the greatest utility. Their designs mean that despite significantly lower ground pressure than all the other vehicles they are able to carry/tow only approximately 20% less than the heavy vehicles but have much greater utility. The ability to configure the vehicles in either personnel or cargo carrying mode and to use attachments such as a HIAB crane or snow clearing blade mean that the vehicles can carry out a far greater range of tasks. This is important both during traverses but also in terms of general use at, or close to Scott Base. Depending on the specific vehicle they can be used to clear and improve routes, to prepare snow runways, to carry passengers and in the case of the Pisten Bully 300 and Berco TL6 can provide basic accommodation for personnel.

These different vehicles have been successfully used by a number of different NAP's as the prime movers in traverse operations. Determining the most appropriate for use by Antarctica New Zealand requires the development of detailed user and functional requirements, examination of the extent to which each vehicle type meets the requirements and a cost benefit analysis of the different options that includes Whole of Life costs not just capital costs.

Cargo Carrying Sleds

The payload efficiency of a given tractor and sled configuration is measured as the weight of payload divided by the towing force (Lever & Weale, 2012). The towing resistance of a sled depends upon; the sliding friction; snow compaction resistance and; plowing resistance. Of these sliding friction is the most significant factor. It is high at the start of a pull, but drops over the first 30 minutes of travel as a layer of water forms on which the sled can travel develops due to friction (Weale & Lever, 2012). An optimal sled design is one that minimises weight, sliding friction and ground pressure; obtains uniform ground pressure; maximises the sled length and maximizes the thermal budget of the sled.

In addition to the towing resistance of a sled other factors which should be considered when determining the most appropriate to use include; ease and amount of maintenance required; cost; equipment life; ride quality; ease of transport, and storage space required. Ride quality is particularly important where personnel modules or fragile or hazardous loads are being carried. Environmental considerations are also high and the potential for spillage of any load must be considered.

There are 2 basic different sled types; rigid steel sleds with narrow skis and; flexible high molecular weight polyethylene (HMWPE) sleds with large contact areas (Weale & Lever, 2008). A typical rigid sled is shown at

Figure 2. HMWPE sleds come in 2 main variants; those where the cargo is strapped directly to the HMWPE and Air Ride Cargo Sleds (ARCS) where the HMWPE layer is overlain by air filled pontoons housed in fabric pouches that secure the sled to a cargo deck (Lever, Weale, & Durrell, 2014). Figure 3 shows an ARCS sled. A breakdown of the main characteristics of these sleds is at Annex D.

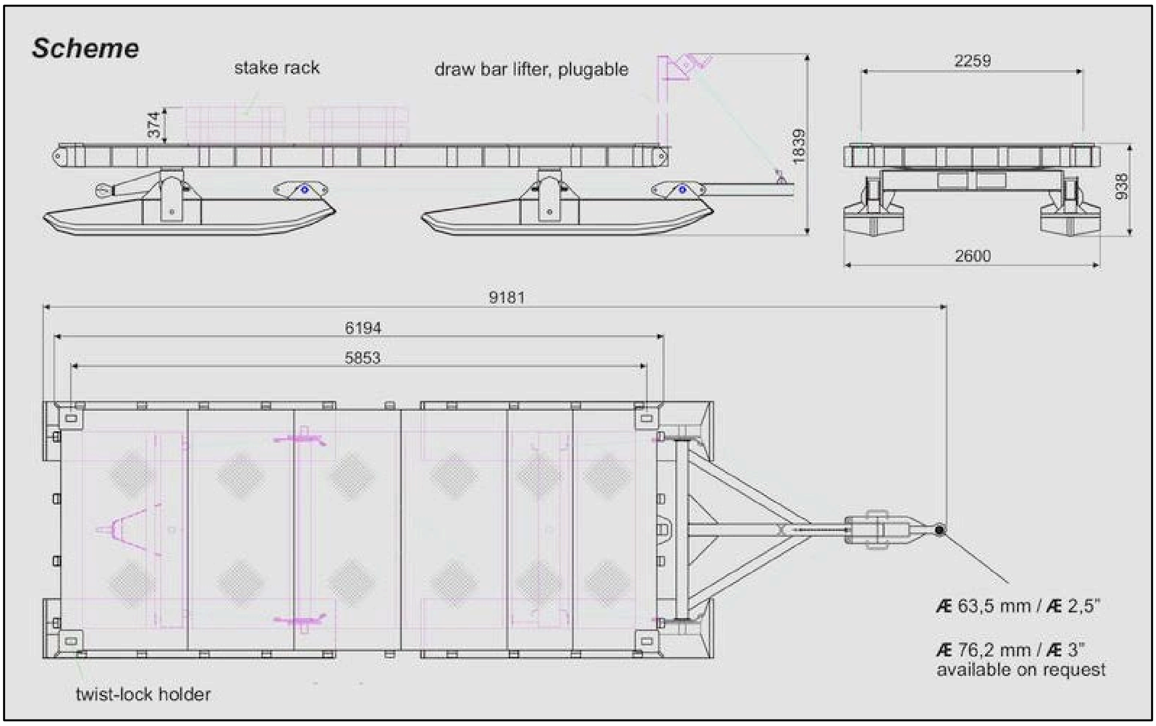

Figure 2. Technical drawing showing the design of a Lehmann sled. From http://www.lehmann-maschinenbau.de/web/index.php?id=34&L=1.

Figure 3. Air Ride Cargo Sled showing the wooden cargo platform fixed to air beams lying on a HMWPE sled. From Lever, Song, & Weale, 2014.

A summary of the advantages and disadvantages of these systems is at Table 3 below.

Sled Type	Advantage	Disadvantage
Rigid	• Robust construction. • Long life span. • Easy to maintain	• Heavy with relatively narrow skis. Small contact areas result in high local ground pressure and poor towing performance • High conductivity means they dissipate heat

		due to friction quickly. • Poor ride quality - prone to digging in. • Expensive ($100,000 per sled)
Flexible HMWPE	• Lightweight • Low cost • Good strength and durability over large sastrugi. • Low towing resistance. • Easy to transport – low volume.	
Flexible HMWPE Air Ride Cargo System	• Lightweight • Low cost • Good strength and durability over large sastrugi. • Low towing resistance. • Easy to transport – low volume.	• Short life span • Design still being refined to remove concerns about wear on pouches and improve cargo decks.

Table 3. Comparison of the advantages and disadvantages of different sled types.

The use of HMWPE sleds have resulted in significant improvements in the size of loads able to be towed by each traverse vehicle (Lever & Weale 2012). In both the standard configuration or as the ARCS the effectiveness of both types is well proven. During the 2012/13 South Pole Traverse, two ARCS sleds travelled 1000 miles with no leaks and worked well over sastrugi (Lever, Song & Weale, 2014).

Sled designs continue to evolve with modular sleds that can carry both fuel and cargo being developed and tested in Greenland in 2014 (Polar Field Services, 2014). Following the South Pole Traverses undertaken over summer 2014/15 further improvements to the design of the fabric pouches used in ARCS will be made to ensure they are strengthen to avoid (T Thomas, personal communication, February 11, 2015). The intent of the USAP is to remove rigid sleds from the South Pole traverse fleet in the next year, although some users retain concerns about their ability to repair the sled should inaccessible air beams become deflated (M Owen, personal communication, December 31, 2014).

The benefits that HMWPE sleds offer in terms of improved ride quality, low towing resistance, low cost and ease with which they can be configured to different sized loads far outweigh the benefits of the more robust longer lasting rigid sleds. Both for transportation of fuel and cargo they have been used successfully even without the ARCS (British Antarctic survey, 2014). A critical component of any long distance traverse capability, like the medium weight vehicles, detailed evaluation of user and functional requirements is required to inform the size and design of standard HMWPE and ARCS sleds needed. This will ensure they are compatible with the majority of likely loads and the needs of any unusual loads are met.

Fuel Supply and Distribution

When fully laden and /or towing loads traverse vehicles, regardless of type consume large amounts of fuel compared to when unladen. Fuel consumption calculations for a representative range of field/traverse vehicles based on a traverse to and from a site 1000km away are shown at Annex E. Even without including fuel for heating and other systems a traverse comprised of a small number of medium or light weight vehicles would require between 10,000 and 20,000 litres of fuel. Additional fuel required would depend on the scientific project being undertaken. In the case of the type of hot water drilling planned for the Vulnerability of the Ross Ice Shelf in a Warming World Programme, drilling and maintaining for 10 days, 3 holes would require 24,000L of fuel (T Bean, personal communication, 17 February 2015). This does not include fuel for electricity used at the site.

Refuelling in the field is currently generally undertaken using 205L drums. This is inefficient due to the lost space when the drums are stacked (a Lehman sledge will carry 40 drums), the amount of waste that is generated and must be disposed of, and the amount of time, manpower and equipment required to load and secure the drums for transport. The risk of fuel spillage is also high since when using this system as it uses an open hose system.

When moving large volumes of fuel, bulk transportation and storage is preferable. It minimises lost storage space, reduces waste, increases the efficiency of loading and unloading. The potential for multiple small spills is reduced by using systems fitted with closed valves.

Bulk tanks comprise either rigid metal tanks or fabric tanks manufactured of puncture resistant rubberised fabric. When used in traverses the former are mounted on skis for transportation, flexible tanks are strapped to HWDPE sleds (Figures 4 and 5). Bulk tanks used by the USAP on their initial South Pole and Greenland traverses have a capacity of 11,356 litres (Leaver & Weale, 2011). Fuel bladders are available in a range of sizes, some small enough to be transported by helicopter. BAS use 5800 litre versions and the USAP use 11,600 litre versions. One x 5800 Litre bladder carries the equivalent of 29 x 205L drums. These are transported on sheets of HMWPE 21m x 2.5 m. This enables 23,200 litres of fuel to be carried on one sled.

Figure 4. 15000L fuel tanks mounted on a Lehmann Sled. From http://www.lehmann-maschinenbau.de/web/index.php?id=34&L=1.

Figure 5. 8 x fuel bladders being towed on HMWPE sleds. From Lever, Song, & Weale, 2014.

Details of these systems are at Annex D. A comparison of the main advantages and disadvantages is at Table 4.

Tank Type	Advantages	Disadvantages
Rigid Cylindrical	• Long life span. • Double skinned.	• Repairs require hot work. • Heavy when empty. • Heavy with relatively narrow skis. Small contact areas result in high local ground pressure and poor towing performance. • High Cost (3 x cost of bladder and HMWPE sled)
Flexible Fuel Bladders	• Durable and flexible. • Lightweight when empty. • Able to be rolled up for transportation when empty. • Variety of different sizes available • Low cost • Easy to repair. Does not involve hot work. • Low ground pressure when transported on HMWPE sleds.	• Single skinned. • No built in containment system. When static need to build bunds around bladders and line the bunds to ensure spills can be contained. • Likely to have a shorter life span than steel tanks.

Table 4. Comparison of the advantages and disadvantages of rigid and flexible bulk fuel tanks.

As the table above illustrates, flexible fuel bladders have significant advantages over rigid tanks. Although fuel bladders are single skinned, they are very effective and robust. They have been used extensively in Antarctica and due to their flexibility have retained their integrity in incidents where less flexible metal structures have suffered breakages (T Thomas, personal communication, February 11, 2015). Combined with HMWPE sleds flexible fuel bladders enable large volumes of fuel to be transported very efficiently. A single medium tracked vehicle can tow 46,400 litres of fuel. The same vehicle could only tow 30,000 litres of fuel in rigid 15,000 litre tanks and 16,000 litres of fuel in drums mounted on 2 x Lehman Sleds. Fuel bladders are the most efficient means of delivering the quantities of fuel required to support the drilling required as part of the Vulnerability of the Ross Ice Shelf in a Warming World Programme.

Accommodation Modules

Critical factors in ensuring that traverse operations are conducted safely and as efficiently as possible include; ensuring that crew members are able to rest well; that only the minimum required time is occupied at each halt; and that disruption and delays due to bad weather are kept at a minimum. A means of achieving this is removing the need to establish field camps at each halt by the inclusion of sled mounted accommodation and support modules in the traverse. This has a number of significant benefits (Garrod, 2012). These include reducing the time taken to establish and break camp; enabling travel in conditions where putting up or taking down tents may be difficult and travel might be avoided and; allowing equipment to be moved short distances at regular intervals during storms, reducing the likelihood of it becoming snowed in (T Thomas, personal communication, February 11, 2015). In addition to the advantages gained during transit these modules can be used to form modular camp structures, which provide high quality working/living environment in field camps. Since they are suitable for fixed mounting of renewable energy generators (e.g. solar hot water or wind turbines) they can also support the reduction of fuel use in a field camp.

A range of systems built with a variety of construction materials are in use by the NAP's. These serve as living vans, science labs, communications centres, and as generator vans to provide power to other accommodation modules and equipment. They vary in shape, size, weight and the amount, type and quality of fixtures and fittings. They include lightweight sometimes air portable modules such as Weatherhaven tents (Figure 6) or fibreglass igloos, to heavier modules based constructed from insulated panels or ISO shipping containers (Figure 7).

Figure 6. Weatherhaven Tent being transported on an ARCS sled. From Garrod, 2012.

Figure 7.Accomodation Module being carried on a Lehman Sledge. From British Antarctic Survey, 2014.

Accommodation modules they range from basic ones such as those currently held by Antarctica New Zealand to those which include, accommodation, snow melting systems and heating systems that provide hot and cold water, cooking facilities, rest areas, workshop areas, toilet and washing facilities including showers. They also include inter vehicle communications systems which enable them to be safely used to transport passengers. Details of the module recently procured by BAS are at Annex F. An overview of the characteristics of available systems or recently procured systems is at Annex D.

With improvements in ride quality associated with the ARCS, the USAP intend to transfer their modules from rigid steel sleds. It is hoped this will enable crew to sleep during transit enabling 2 shifts to be operated and the number of hours travelled each day to be increased (T Thomas, personal communication, February 11, 2015).

In addition to the facilities contained within the module, significant additional factors that should be considered when evaluating potential options include the ease of transportation and weight. Ideally standard ISO container size should be used to aid in transportation and weight should be minimised to enable the module to be easily moved by HIAB crane or dragged off a sled. It should be noted that as seen at Annex F that space limitations related to fitting to a standard container size can be overcome by incorporating elements which can be assembled onto the super structure once it is on a sled.

A summary of the main advantages and disadvantages of the basic and fully fitted modules is at Table 5 below.

Support Module	Advantages	Disadvantages
Basic	• Simple design, low cost, short lead in time. • Durable structures with a proven long life-cycle • Easily re-configured to suit different purposes/tasks. • Low cost.	• Many daily tasks like snow melting can only take place during halts. • Many tasks still need to be undertaken outside the module. • Little comfort compared to fully fitted systems.
Fully Fitted	• Maximum use of available space achieved through detailed design process. • High level of comfort able to be achieved. • Ability to conduct basic tasks like snow melting on a 24 hour basis. • Durable structures with a long life-cycle.	• Bespoke design increases lead in time. • Integration of multiple systems increases amount and complexity of maintenance. • High cost.

Table 5. Comparison of the advantages and disadvantages of basic and fully fitted accommodation/support modules.

The improvements in crew effectiveness and the efficiency of traverse operations that result from using bespoke fully fitted accommodation and support modules mean that the further and longer a traverse is travelling the more important they become. Lightweight, less complex, basic modules are suitable for short overland trips (2 to 3 days) where the cumulative strain on crews is less. For longer duration traverses such as the 1000km traverse to site 1 in the Vulnerability of the Ross Ice Shelf in a Warming World Programme, the advantages of fully fitted accommodation modules outweigh the disadvantages of high cost, increased complexity and long design and development phases associated with them.

Crevasse Detection and Avoidance

Effective route finding and navigating is a key factor in determining the efficiency of a traverse. This comprises two main elements, route recce and crevasse identification. A critical component of this is detecting and avoiding hidden crevasses in order to avoid unnecessary delays or accidents.

For initial route reconnaissance High Resolution Synthetic Aperture Radar and High Resolution Optical Imagery should be used prior to departure to identify the route which offers the lowest risk of crevasses (W Rack, personal communication, February 11, 2015). For ground based assessment crevasse detection is undertaken using Ground Penetrating Radar (GPR) systems that use a 400Mhz antenna (N. Bell, personal communication, February 05, 2015).

To reduce the risk associated with this process unmanned vehicles have been developed to conduct GPR surveys to detect under surface hazards in polar ice sheets (Lever et al., 2013). These systems navigate by GPS waypoints and conduct surveys across pre-planned routes before wirelessly transmit the results to an operator. At present these systems can only operate for limited periods of time and although successful trials have occurred, have yet to be employed in traverse operations (Lever et al., 2013).

In current traverse operations GPR equipment is used in one of 2 different configurations:

1. **Mounted on a Light/Medium Weight Vehicle**. The antenna is mounted 2-3m ahead of the lead traverse vehicle via a metal frame attached to the front of the vehicle (Figure 8). Information is transmitted from the antenna via a cable to a monitor mounted in the vehicle cab. Data analysis and interpretation is undertaken by a crew member in the passenger seat (Lever et al., 2013a). Lead vehicle is one with low ground pressure. Commonly used vehicles are the Pisten Bully 100, Pisten Bully 300 and the Prinoth Everest.
2. **Skidoo Mounted**. The antenna and associated wheel are mounted on a small sled fixed to a skidoo. Information is transmitted from the antenna via a cable to a monitor mounted in front of the driver. Data analysis and interpretation is undertaken by the skidoo driver. The skidoo operates in advance of the main traverse. Risk associated with the skidoo falling down a crevasse is mitigated in high risk areas by travelling in linked pairs (British Antarctic Survey, 2014).

Both these systems give the operator has only a short “2-3 second” to identify an approaching hazard and to tell the driver to stop (Lever, Ray, Morlock, Burzynxki, & Williams, 2013b). Consequently this is a task that requires an experienced operator with a good knowledge of ice/glacier behaviour.

Figure 8. Photograph showing a crevasse detection system in which the GPR antenna is located in a container surrounded by an inflated inner tube. This is attached to the front of the vehicle by a metal frame. From USAP.

Figure 9. Photograph showing the skidoo mounted crevasse detection system used by BAS. From Garrod, 2012.

A summary of the main advantages and disadvantages of the two configurations is at Table 6 below.

GPR Configuration	Advantages	Disadvantages
Mounted on lead vehicle	• Crew member responsible for data analysis and interpretation can focus completely on the task. • Crew are not exposed to the weather. Can conduct survey in bad weather.	• Limited reaction time so stressful for both radar operator and vehicle driver. • In high risk areas would need to attach the vehicle to one of the main traverse vehicles for safety. Slows the speed of the whole traverse.
Mounted to side of a skidoo	• Operates ahead of the main traverse. This allows the traverse to maintain its speed as the route is cleared ahead of its passage. • Uses low ground pressure and low weight vehicles reducing risk of falling in a crevasse. • Highly mobile. Enables high risk areas to be examined using search patterns without affecting overall speed of operation.	• Operator has to analyse and interpret data at the same time as driving the skidoo. • Sunlight can make it difficult to view the monitor. • Operator is exposed to the weather. May be unable to deploy the system in bad weather conditions where crew in a closed compartment could still operate.

Table 6. Comparison of the advantages and disadvantages of GPR systems mounted on skidoos or the lead vehicle in the main body of a traverse.

The most commonly used 400Mhz GPR data acquisition systems are the Sir-30E and the Sir-4000 manufactured by Geophysical Survey Systems Incorporated. A comparison of the main characteristics of the systems is at Annex G. Both systems offer similar capability, but due to its size and weight the Sir-30E cannot be used in the skidoo mounted role. The Sir-4000 can be used in both roles. The Sir-4000 has the further benefits of being the lower cost of the 2 variants and of being able to operate with both the analogue currently in use and digital antennas which are expected to reach the market soon (N Bell, personal communication, February 05, 2015).

As shown in Table 6, both the skidoo mounted and light/medium vehicle mounted GPR configurations have a number of advantages and disadvantages. Depending on weather conditions, availability of GPR operators, likely crevasse risk and distance to be cleared both configurations have utility. In good weather where maintaining the speed of the traverse is important and only short distances need to be cleared then the skidoo mounted system may be preferable. To clear long routes over periods of time where operator fatigue and or weather may become a factor, the ability to operate a system from within a vehicle would be preferable. To obtain the optimal mix of equipment and enable both configurations to be used depending on the task then the Sir-4000 should be used. Once the mountings for the equipment have been manufactured the GPR equipment can be changed between them. This will bring utility to a wide range of Antarctica New Zealand operations not just long distance traverses.

Discussion

Total Traverse Capability

Based on the review of component parts of traverse capability and understanding of constraints affecting the development of the capability it is estimated that to support drilling 1000km from Scott Base that the following mix of equipment would be required to move all critical components, supplies and fuel to and/from the site by land traverse.

Capability	Quantity	Equipment	Remarks
Crevasse Detection	1	Ground Penetrating Radar Sir-4000.	
	1	Lightweight tracked vehicle &/or Skidoo	Pisten Bully 100 or BV206
Cargo Carrying/Towing	2	Medium weight tracked vehicle	PB300, Berco TL6 or Prinoth Everest.
Crew Accommodation	1	20" Accommodation and Support Module.	Sled Mounted
Equipment support/spares store	1	3m Storage Container	Mounted on rear of Berco TL6, Pisten Bully 300 or on a sled.
Traverse Consumable store	1	Refrigerated 3m ISO Container	Sled mounted.
Cargo Transport	2	ARCS Sled or Rigid Sled	
Bulk Fuel Transport	2	HMWPE Sled (21m x 2.5m)	
	8	5678 Litre Fuel Bladder	

Table 7. Basic component parts of a self-supporting traverse able to travel 2000km.

This equipment would be operated by a minimum crew of 6 including at least one experienced GPR operator. It would have the capacity to tow 46,400 litres of bulk fuel. In addition to being able to tow the accommodation module, a further approximately 20,000kg of cargo could be carried on the vehicles and the sleds. This would enable the drill components (6000kg) and at least a further 14,000kg of stores to be carried. This is deemed sufficient to be able to carry field camp infrastructure, equipment spares, fuel drums, food required to support a traverse crew of 6 for at least 30 days and a science party of 10. Depending on the vehicle chosen in cargo carrying mode this equipment could carry between 6 (using the Pisten Bully 300) and 14 people (using the Berco TL6) including the crew. Additional personnel could be transported in the accommodation module and/or in rear passenger compartments if fitted to the Berco TL6 or Pisten Bully 300. This equipment would have the ability to load and unload cargo weighing up to 3000kg, and to clear snow/prepare routes and landing strips. The addition of a further HMWPE sled would enable spare Skidoos for field use to be easily transported.

Estimated capital costs of the equipment are at Table 8. The cost of ARCS is not included as these are built to order and the manufacturer did not provide estimates. These costs represent averages of those shown in Annexes C, D and G where several products are available. The costs of spares or of additional components and labour required to mount equipment on vehicles (e.g. GPR equipment) are not included. For detailed planning, estimates can be obtained from the suppliers and manufacturers listed at Annex H.

Equipment Type	Estimated Cost Per Item (NZ$)	Quantity	Total Cost NZ$	Remarks
Ground Penetrating Radar Sir-4000.	45,000	1	45,000	
Lightweight Tracked Vehicle	300,000	1	300,000	Pisten Bully 100 or BV206
Skidoo	15,000	1	15,000	
Medium weight tracked vehicle	500,000	2	1,000,000	PB300, Berco TL6 or Prinoth Everest.
20" Accommodation and Support Module.	200,000	1	200,000	
3m Storage Container	5,000	1	5,000	
Refrigerated 3m ISO Container	10,000	1	10,000	
Rigid Sled	60,000	2	120,000	
HMWPE Sled	7,000	2	14,000	
5678 Litre Flexible Fuel Bladder	11,000	8	88,000	
Total Cost			**1,797,00**	

Table 8. Cost of all the component parts of a self-supporting traverse able to travel 2000km.

Total cost if all this equipment was purchased new is approximately NZ$1.8 Million. This is likely to be reduced if ARCS sleds were purchased rather than rigid sleds. Utilising existing platforms within the Antarctica NZ fleet would enable the capital cost of developing the capability to be further reduced. Using the existing Pisten Bully 300 as a load carrying towing vehicle and one of the Pisten Bully 100/BV206 fleet and an existing Skidoo to form the Crevasse Detection capability would reduce costs significantly. Using the current containers and Lehmann sleds would also reduce cost and would leave only the equipment in Table 9 to be purchased new.

Equipment Type	Estimated Cost Per Item (NZ$)	Quantity	Total Cost NZ$	Remarks
Ground Penetrating Radar Sir-4000.	45,000	1	45,000	
Medium weight tracked vehicle	500,000	1	500,000	PB300, Berco TL6 or Prinoth Everest.
20" Accommodation and Support Module.	200,000	1	200,000	
HMWPE Sled	7,000	2	14,000	
5678 Litre Flexible Fuel Bladder	11,000	8	88,000	
Total Cost			**847,000**	

Table 9. Cost of equipment required to augment existing Antarctica New Zealand in order to develop a self-supporting traverse able to travel 2000km.

Total cost of this equipment is approximately NZ$ 850,000. The majority of the cost is a purpose built accommodation module and a second medium weight tracked vehicle. This mix of equipment does not take advantage of the improved performance of ARCS sleds over rigid sleds. If it was chosen to purchase these rather than use existing Lehmann sleds the costs would be higher, though unlikely to reach NZ$1million.

Capability Development

The time taken to develop traverse capability depends upon a number of factors including; the time taken to supply equipment; the available budget; availability of transport to Antarctica and availability of staff to conduct integration work including mechanical work; development and delivery of training and development of operating procedures. Depending on the available budget, two main approaches to procurement and development of the capability could be taken. These are as follows:

1. **Single Phase of Procurement**. All equipment is procured in financial year 2014/15. It is delivered to Scott Base in summer season 2015/16, configured and trialled. Full traverse capability is able to support the drilling at site 2 in season 2016/17.
2. **2 Phases of Procurement**. Procurement of equipment is split to spread costs across 2 financial years. GPR equipment, a medium wheeled vehicle, HMWPE sleds and fuel bladders are purchased in financial year 2014/15 to ensure delivery to Scott Base in summer season 2015/16. Equipment is configured and trialled in season 2015/16. It is used to conduct a traverse in season 2016/17 to drilling site 2 using existing basic accommodation modules. A fully fitted accommodation/support module is procured in FY 15/16 and delivered to Scott Base in season 16/17. It is trialled in season 16/17 and is ready to support the traverse to drill site 1 in summer season 2017/18.

In both cases, the short procurement/lead time of the GPR equipment means that it could be purchased early in financial year 15/16 but still delivered to Scott Base in summer season 2015/16. This may aid budgeting depending on the available CAPEX. Since GPR equipment is easily transported by air, it could still be delivered early in season 15/16 and the capability utilised for the majority of the season.

Taking a phased approach to the implementation of this capability would enable costs to be spread not only now but in the future as component parts can be gradually replaced over a number of years. This approach would also enable the gradual development of the necessary in house understanding and technical skills etc. required to maximise the potential of the traverse capability. Maximising use of existing equipment will reduce risk associated with investing in new technology e.g. ARCS sleds, by enabling the technologies to mature and understanding of user requirements to be developed through field traverse experience. The main disadvantages of this approach are that it would take longer to establish the full capability, and the capability may be limited due to the age and possible mechanical unreliability of existing platforms.

Conclusion

The addition of a medium weight tracked vehicle like the Pisten Bully 300 or Berco TL6, Sir-4000 GPR equipment, 8 x HMDPE sleds, 8 x 5678litre fuel bladders and a fully fitted mobile accommodation module to the existing equipment fleet, would enable Antarctica New Zealand to develop a long distance traverse capability. The traverse capability would be based on 2 medium weight vehicles and a lightweight vehicle. Crewed by a minimum of 6 people it would be able to support parties on traverses at least 2000km long, and field parties conducting drilling operations that use up to 30,000L of fuel. By using low ground pressure, high power vehicles to tow the sleds, the traverse would be capable of travelling at least 10km/hour under normal conditions. This would double the speed of previous short distance traverses conducted using bulldozers as the prime load towing vehicle. Using only 2 vehicles from the current Antarctica New Zealand fleet the impact on other logistics operations would be kept to minimum. The ability to alternate GPR equipment between a lightweight vehicle and a skidoo would provide the flexibility to deploy a crevasse detection capability in different configurations depending on conditions. Like the medium tracked vehicle, this additional capability could also be used to support other operations when not being used in a traverse. This would greatly enhance the capacity of Antarctica New Zealand to conduct operations independently of other NAP's.

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List of Antarctica New Zealand Transport Equipment*

Caterpillar D4 tractor bulldozer 2002
Caterpillar D6 tractor bulldozer 1996 (refurbished 2013)
Caterpillar Fieldchief 926 wheel loader
Merlo Telehandler 2013
Hagglund Bv206 2005
Hagglund Bv206 2005
Hagglund Bv206 2005
Hagglund Bv206 2013
Isuzu Cargo/Fuel truck 1996
Piston Bully PB100 Kassbohrer 2002
Piston Bully PB100 Kassbohrer 2002
Piston Bully PB300 Kassbohrer 2006
Yamaha BigBear 4WD quadbike 1998
Yamaha BigBear 4WD quadbike 2007
Yamaha BigBear 4WD quadbike 2006
Bombardier Skandic skidoo 2003
Bombardier Skandic skidoo 2003
Bombardier Skandic skidoo 2003
Bombardier Skandic skidoo 2003
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Bombardier Skandic skidoo 2010
WT550 Skandic Skidoo 2012
WT550 Skandic Skidoo 2012
WT550 Skandic Skidoo 2012
WT550 Skandic Skidoo 2012
Toyota Landcruiser 2005
Toyota Landcruiser 2007
Toyota Landcruiser 2011
Toyota Landcruiser 2011
Toyota Landcruiser 2012
Toyota Hilux flatbed truck 2001

*Only includes equipment at Scott Base.

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<u>Principal Traverse Tasks</u>

Primary Task	Sub Task
Tow sleds	
Transport loads to and from field camp	Transport personnel (crew and science staff)
	Transport fragile goods including science equipment
	Transport hazardous goods
	Transport fuel for use in camp and en route.
	Transport food for use in camp and en route.
	Transport field camp infrastructure.
	Transport science samples & waste
Load/Unload on/off sleds and vehicles	
Identify, mark and maintain a route	Conduct route reconnaissance
	Identify and avoid crevasses
	Be able to remedy any route problems e.g.. Backfill crevasses
	Prepare route
	Mark the route
Maintain all vehicles and support equipment	Transport spare parts and specialist tools and test equipment.
Recover vehicles	
Support crew for duration of operation	Accommodate the crew
	Enable crew to prepare and cook food.
Support science tasks on route	
Communicate between vehicles in the traverse and with base.	
Prepare snow landing strip for aircraft	

Summary of Cargo Carrying or Sled Towing Vehicles

Name	Category	Engine Size (Litres)	Engine power (HP)	Fuel Capacity (Litres)	Fuel Usage (Litres/Km)	Speed (km/h)	Gross Weight (kg)	Unladen Weight (kg)	Carrying Capacity (kg)	Towing Capacity (kg)	Ground Pressure (psi)	Draw bar Pull (lbs)	Draw bar Pull/weight	Dimensions: Length (m)	Dimensions: Height (m)	Dimensions: Width (m)	Crew
Caterpillar D6N LGP	Bulldozer	6.6	173	299	5	Max 11	18096				4.7	39341 at 5.7km/h 21806 at 10km/h		5.18	3.202	3	1
Caterpillar D4H LGP	Bulldozer	5.2	95	167		Max 10.2					4.2			4.93	3.03	2.76	1
Case Quad Trac 535	Heavy Tracked Vehicle		500	1170	8.38 (heavy load) 5.31 (light load)	Max 16	25401kg	24292			5.4 psi - 7.8 depending on variant	25-29000	ranges from 0.42 to 0.33	7.62	3.96	3.91	
Caterpillar – MT865	Heavy Tracked Vehicle	18	510	1249		Max 39.7 (unladen)					5.96	41871	0.45	6.75	3.5	3.57	
Caterpillar – Challenger MT 765B	Heavy Tracked Vehicle		320	446 or 787	9.2	Max 40 (Unladen)	16329	14,095		40000		25000		5.917	3.444	3.376	
Tucker SnoCat	Medium Tracked Vehicle		140	189 or 378			6622				1.8	8000		7.31	2.92	2.64	
Pisten Bully 300 Polar	Medium Tracked Vehicle	12.8	455	370 plus 2 x 80 l auxillary tanks	2.8- 3.9	21 (Max) 9 (Towing)	12,000	8400	2,500	40000	0.9 -1.2		0.61 =/- 0.06 (5)	6.98	2.930 (with cab tilted = 3.385)	4.26 (5.5m with blade)	2
Prinoth Everest	Medium Tracked Vehicle		430	290	2	24 (Max) 10 (Towing)	12500	9,670	2830	50000	1.23			5.5 (6.8 with blade & hitch)	2.935	4.26 (5.58 with blade)	3
Berco TL-6	Medium Tracked Vehicle	5.9	250	245	3.5	50 (Max) 12-13 (towing)	11000 (5500 front car, 5500 rear car)	6760 (4600 front car, 2160 rear car)	4240 (900 front car, 3340 rear car)	>23000	2.61			7.9 (front & rear)	2.92	2.2 (w/o blade)	6
Pisten Bully 100	Light Tracked Vehicle	4.82	197	150	2.3l	Max 25	6200		1500	4500				5.743 (w/o blade)	2.5	3.1 (with widest tracks)	
Haagland BV206	Light Tracked Vehicle	3.2 or 2.4	135 or 90		1	max 55 or 40	6540 (3270 front and 3270 rear)	2770 front and 1030 rear	500kg and 2240	2500	1.68 -1.97			6.9 (front & rear)	2.4	1.87	5

Name	Ancillaries: HIAB Crane	Snow Blade	Excavator Bucket	Transportation Bucket	Electric Winch	Passenger cabin/living module	Load Changer	Flat bed	workshop module	fuel transportation module	NAPs/Organisations using vehicles: Norway	Sweden	British Antarctic Survey	Australian Antarctic Division	China	Chilie	USAP	NZ	South Africa	ALE	Capital Cost (NZ$)	Main References
Caterpillar D6N LGP		x																	x			1
Caterpillar D4H LGP		x																				
Case Quad Trac 535		x															x				603000	2, 3, 4, 5
Caterpillar – MT865	x														x						724000	2, 6
Caterpillar – Challenger MT 765B													x	x	x		x		x		624000 (2013 price)	3,7
Tucker SnoCat																	x				303000	4
Pisten Bully 300 Polar	x	x		x	x	x							x								500000	8, 9, 10
Prinoth Everest		x	x		x						x						x			x	400000	9, 11
Berco TL-6	x	x	x		x		x	x	x	x	x	x									620000	12, 13
Pisten Bully 100		x				x											x				295000	4
Haagland BV206																						14

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Summary of Available Accommodation/Support Modules, Sleds and Fuel Transport Equipment

Type	Description	Capacity (L)	Weight (kg)	Dimensions (m)	Manufacturer	Cost ($ NZ)*	Remarks	Reference
Accommodation Modules								
Norwegian Accommodation Module	Sleeps 6 with kitchen. Uses standard ISO container mountings.			L 6.290 x W 2.598 x H 2.604	Scandanavian Terrain Systems	197683	Lead time 6 months. Additional airborn heating system $1591	1. Quotation ref: 50252
BAS iSTAR Accommodation Module	Sleeps 6 with kitchen. Uses standard ISO container mountings.				Kalliope UK	165410	Additional modilfications - snow melter $16000.	2
BAS Ronne/Filcher Accommodation Module					Kalliope UK	88000		2
Summit Camp Living & Energy Module	2 separate modules. Accomodation for 8.		22500			221285.5		3
SPoT Living and Generator Modules	2 separate modules				Kucher Electrical	167640.5		4
Tool Shed/Food Module	2 separate modules					73761.5		4
Sleds & Fuel Transport Equipment								
Scandanavian Terrain Vehicles Rigid Sled	20 feet, loading capacity 12 ton, weight 3200kg.		3200kg empty, 12000kg full		Scandanavian Terrain Systems	62870		1
Lehman Sled (15T variant)			empty 3500kg 15000kg full				25T version (3700kg tare) and 10T versions (3100kg tare) also available.	5
10T Cargo Sled			empty 1360kg, full 10432			150000		3
Air Ride Cargo Sleds					Federal Fibers.		Varying sizes built to order for USAP.	6
Tank Sled		11356	empty - 5629, full 14995			150000		3
Bladder Sled (3000 gallon)	Includes sled and bladder	11356	empty 839, full 10000		Bladders - ATL, Sled - Federal Fibers.	36880		3
Bladder Sled (6000 gallon)	Includes sled & 2 x bladders	22712				40233		4
HWD Sled (BAS)	Used to carry 4 x 5800L bladders)			21 x 2.5	King Plastics Corp	6195		2
Fuel Bladder (1500 gallon)		5678		4.87 x 2.25	ATL UK	10651		2

* Based on a conversion US Dollars to NZ Dollars of 1:1.34

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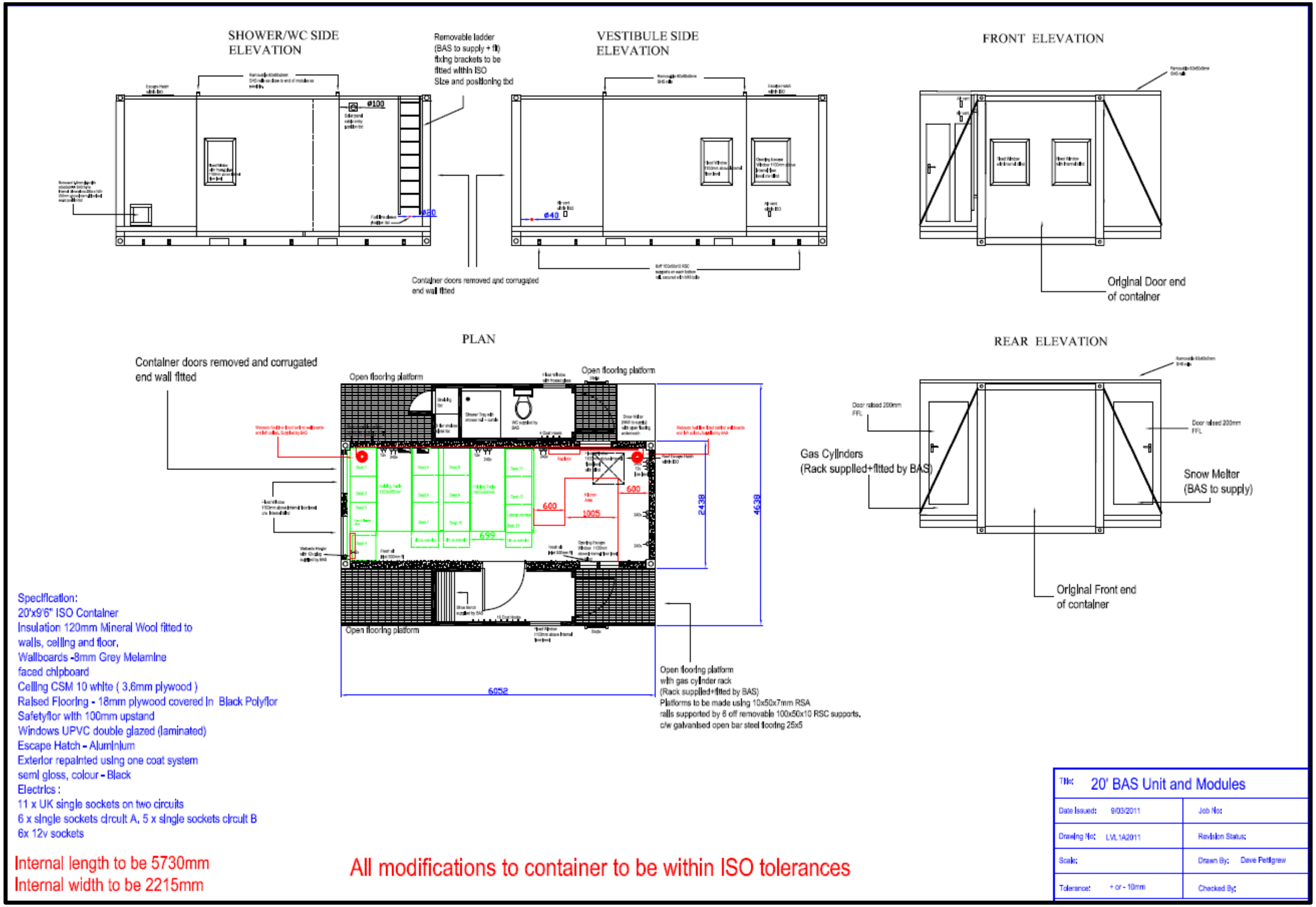
6. Personal Communication, D Retter, February 04, 2015.

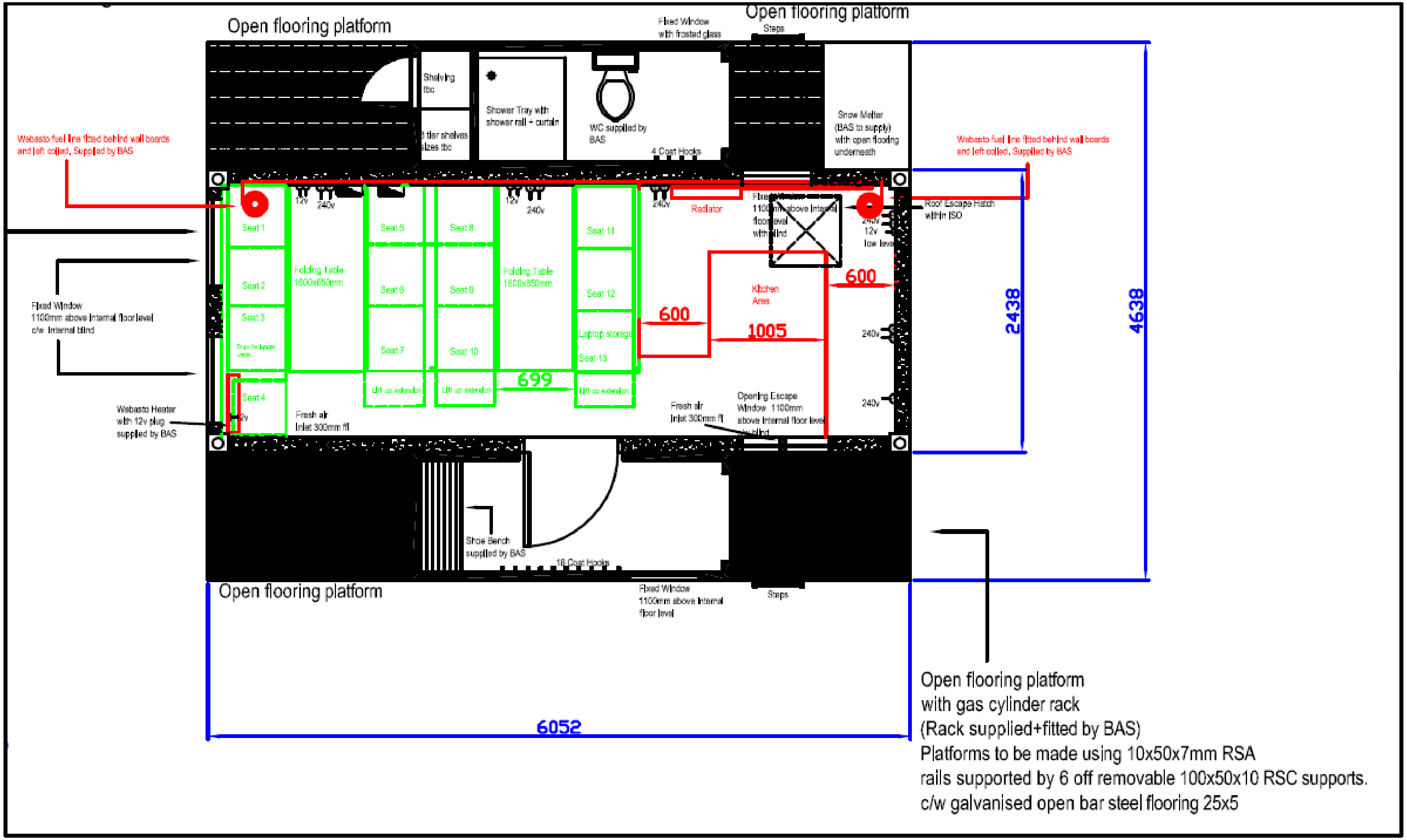
Fuel Demand Calculations

Vehicle	Fuel Consumption (Litres/km)	Total Fuel consumed over 2000km (Litres)
Prinoth Everest	2	4000
PB300	3.9	7800
Berco TL6	3.6	7200
PB100	2.3	4600
BV206	1	2000
Skidoo	0.43	860

Technical Drawings and Photographs of the iSTAR Accommodation Module



Detail of Plan of Accommodation Module Floor Plan



Drawings courtesy of M Dinn (British Antarctic Survey). Design IP lies with Kalliope UK.

Photographs of the iSTAR Accommodation Module

Internal view showing the kitchen compartment.

View of the module mounted on a Lehman Sled showing the external storage space and vestibule.

Photographs from http://www.kalliopeuk.com/Projects.html#2.

Ground Penetrating Radar Crevasse Detection Systems

Comparison of the Sir-4000 and Sir-30E Antennas

Sir-4000	Sir-30E
Single channel controller	2 channel controller.
Analogue and Digital controller	Analogue controller
Compact	Not compact
Internal Battery	External battery
Lower power needs	Higher power needs
32 bit data collection	16 bit data collection

Information based on personal communications with N Bell, (Allied Associates Geophysical) and M Wilson (ScanTec Ltd).

Breakdown of Equipment Required For Different GPR Configurations

	Configuration		Price US$*	Price NZ$*
	Mounted on a Skidoo Sled	Vehicle Mounted		
Sir 30E		x	27852	37321.68
Sir-4000	x	x	19250	25795
400-Mhz Antenna	x	x	6980	9353.2
Antenna cable	x	x	900	1206
Mount for 4000	x	x	618	828.12
Survey wheel	x		2500	3350
Antenna Cable (external)		x	1400	1876
Bulk head connectors		x	175	234.5
Survey wheel encoder		x	650	871

Total Cost (NZ$) Skidoo	40532.32
Total Cost (NZ$) Vehicle mounted using Sir 30E	50862.38
Total Cost (NZ$) Vehicle Mounted using Sir 4000	40163.82
Total Cost (NZ$) For use in both configurations using Sir 4000	43513.82

*Personal communication, N Bell, February 05, 2015.

Manufacturers of Traverse Equipment

Name	Equipment Type													Contact Details				Website	Remarks
	Flexible Fuel Bladders	Ground Penetrating Radar	Steel Sleds	HMWPE	Air Ride Cargo Sleds	Accommodation Modules	Prime Movers							Point of Contact	Address	Phone	Email		
							Prinoth	Pisten Bully	TL6	BV206	Caterpillar	SnoCat	Case						
Elphinstone			X			X								Cheryl Arnol	36 TASMAN HWY, TRIABUNNA TASMANIA AUSTRALIA	+61 3 6257 3242	cheryla@elph.com.au	www.elph.com.au	
Lyttleton Engineering			x				x							Peter Judd	Lyttelton, NEW ZEALAND	03 328 8105	Email: peter.judd@lytteng.co.nz		NZ suppliers of Prinoth.
Scandinavian Terrain Vehicles AB						X			X	X				Klas Göran Asplund	Box 373, 931 24 SKELLEFTEÅ, Besöksadress, Plastvägen 3, SKELLEFTEÅ	+46 (0)910 29 07 06	klas-goran.asplund@stvab.se	http://www.stvab.se/index.php?id=294&L=1	Suppliers to Swedish and Norwegian Polar programmes.
Penguin Composites Pty Ltd						x									808 South Road, Penguin Tasmania 7316,Australia			WWW.ICEWALL.COM.AU	Suppliers of lightweight fibreglass "Igloo" modules.
Allied Associates Geophysical		x												Norman Bell	Concept House, 8 The Townsend Centre, Blackburn Road,Dunstable, Bedfordshire, ENGLAND, LU5 5BQ	+44 (0) 1582 606 999	norman@allied-associates.co.uk	http://www.allied-associates.co.uk/	Suppliers of GPR equipment to BAS and Ranulph Fiennes Coldest Journey Expedition
Geophysical Survey Systems, Inc.		x																http://www.geophysical.com/	
Kalliope						x								Ian Hunt			kalliope@btconnect.com	http://www.kalliopeuk.com/	Suppliers to BAS
Ski Industries Ltd								x						Ben Quane	304 Cashel Street, Christchurch, New Zealand	+64 3 358 1902	ben@ski-industries.co.nz	ski-industries.co.nz	NZ suppliers of Pisten Bully.
Federal-Fabrics-Fibers, Inc.					x									David Retter		(+01) 978-770-2020	dretter@federalfabrics.com		Suppliers to USAP
Pisten Bully																: +49 7392 900 - 411	harald.haege@pistenbully.com	http://www.pistenbully.com	
Gough Engineering											x							http://goughengineering.co.nz/	
Addis Containers						x												http://www.addis.co.nz/	
William Adams											x			Peter Fewkes				http://www.williamadams.com.au/Pages/Home.aspx	
Pietersen Machinery											x							http://www.petersoncat.com/	Suppliers to USAP
Trelleborg / Dunlop GRG,	X																	http://www.trelleborg.com/en/Dunlop-GRG/	Suppliers to Ranulph Fiennes Coldest Journey Expedition
ATL	x															01 201 825 1400	atl@atlinc.com	http://www.atlltd.com/	
Lehmann Maschinenbau GmbH																		http://www.lehmann-maschinenbau.de/	Suppliers of Cargo Sleds
Brunger Export Inc				x										Robin Brylski	4901 NW 17th Way - 600, Ft Lauderdale, Florida, 33309, USA	01 954 928 1245	rbrylski@brungerexport.com		
King Plastics Corp				x										Dale Givens				http://www.kingplastic.com/	Suppliers to BAS.
Kucher Electrics						x												http://www.specializedmodularservices.com/about-sms	Suppliers to USAP
Roekling Plastics				x														http://www.roechling.com/en/home.html	Suppliers to USAP
Saunders & Ward			x															http://www.saunward.com.au/	